chapter

23 Population Interactions

Individual species do not live and evolve in isolation. They are all members of ecological communities, which are made up of many interacting populations within a physical environment that may itself be changing. Just as individual species exhibit recognizable traits that have evolved over long periods of time, entire ecosystems exhibit clearly identifiable patterns and relationships that not only characterize the interactions of living things with their environment, but are also dynamic in time and space.

The relationships between the members of an ecological community are always changing. They may change gradually, as the ecosystem slowly matures, or abruptly, if it is suddenly disrupted by a significant event. Whatever the case, change is inevitable. While very few species can significantly modify their environment, most have adaptations that can help the organism thrive in a changing ecosystem.

Humans, an intelligent and successful species, are unique among all species. Our use of tools has allowed us to live in environments well outside our biological range of tolerances: we inhabit almost every terrestrial ecosystem on Earth (**Figure 1**). Even so, the human species experiences the same limitations as other species do. Like all populations, humans live in finite environments with limited carrying capacities. Today, the rapidly growing human population and its consumption of resources place significant stresses on those environments.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Study the images in **Figure 1 (a)–(c)** and reflect on the following questions:
   (a) What are some factors that enable the human species to live in different environments?
   (b) What are the key resources needed to support any human population? Where and how are these resources obtained?
2. Compare the ways in which urban populations differ from rural populations in how they obtain resources.
3. What are potential ecological effects on the environment of the activities of large human populations?

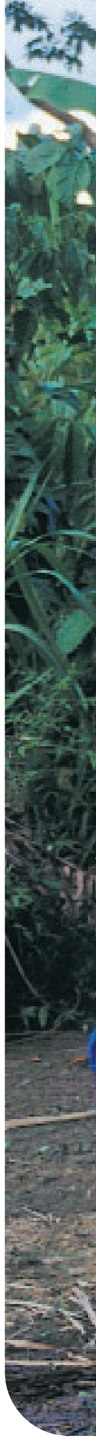

Figure 1
Using our skills to adapt to the environmental conditions, humans now live almost everywhere on Earth.

Exploration — *Effects and Consequences*

With two or three other students, brainstorm some possible effects of the human population on each of the following:

- forests
- grain and livestock production
- wildlife
- water supply and water quality
- biodiversity
- the atmosphere
- harvesting of seafood

(a) Design a concept map to illustrate these effects.

(b) Present your concept map to the class.

23.1 Interactions within Communities

CAREER CONNECTION

Interpretive Naturalist
A career as an interpretive naturalist involves research in natural history and the environment, and also presenting that information to the general public. Most interpretive naturalists work for a park, botanical garden, or wilderness area. This career needs a sound understanding of populations and how they interact in an environment or ecosystem. What kind of training and experience is needed to enter this career?

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Populations do not live in isolation. Within a given ecosystem, populations of different species interact in a community. Within each community, each organism occupies its own ecological niche. Ecologist Eugene Odum describes an organism's ecological niche as its "occupation." For example, on the African savannah, a variety of interactions occur among organisms (**Figure 1**). While the lions, zebras, water buffalo, and antelope all occupy the same habitat, each member of this community uses different mechanisms to survive.

Figure 1
An African grassland community. The African lion's ecological niche includes what it eats, what eats it, the way it reproduces, the temperature range it tolerates, its habitat, its behavioural responses, and any other factors that describe its pattern of living.

Interactions among individuals of different species (interspecific) in a community have important influences on the population dynamics of individual species. Although species interact in various ways, interactions between two species and their effects on the population density can be classified into the five categories shown in **Table 1**. **Symbiosis** includes a variety of interactions in which two species live together in close, usually physical, association. Parasitism, mutualism, and commensalism are types of symbiotic interactions.

symbiosis various interactions in which two species maintain a close, usually physical, association; includes parasitism, mutualism, and commensalism

Table 1 Classification of Interactions between Two Species

Interaction		Effect on populations
interspecific competition		Interaction may be detrimental to one or both species.
predation		Interaction is beneficial to one species and usually lethal to individuals of the other.
symbiosis	• parasitism	Interaction is beneficial to one species and harmful, but not usually fatal, to the other.
	• mutualism	Interaction is beneficial to both species.
	• commensalism	Interaction is beneficial to one species and the other species is unaffected.

Interspecific Competition

Interspecific competition occurs between individuals of different species and restricts population growth. Interspecific competition can occur in two ways. Actual fighting over resources is called **interference competition**. An example of interference competition is the fighting that sometimes occurs between tree swallows and bluebirds over birdhouses. The consumption or use of shared resources is referred to as **exploitative competition**. An example of exploitative competition occurs when both Arctic foxes and snowy owls prey on the same population of Arctic hares.

The strongest competition occurs between populations of species with overlapping niches. The more that niches overlap, the greater the competition between species, as demonstrated by Russian ecologist G.F. Gause. Gause tested the theory that two species with similar requirements could not coexist in the same community. He predicted that one species would consume most of the resources, reproduce efficiently, and drive the other species to extinction. Gause's experiments led to the conclusion that, if resources are limited, no two species can remain in competition for exactly the same niche indefinitely. This became known as Gause's principle, or **competitive exclusion**. In nature, such severe competition is usually avoided by **resource partitioning**, in which different species with similar requirements use resources in different ways—for example at different times or in different places.

The results of interspecific competition take on several forms:

- the population size of the weaker competitor could decline;
- one species could change its behaviour so that it is able to survive using different resources;
- individuals in one population could migrate to another habitat where resources are more plentiful.

In any of these cases, competition would decline.

interspecific competition competition between individuals of different species

interference competition interspecific competition that involves aggression between individuals of different species who fight over the same resource(s)

exploitative competition interspecific competition that involves consumption of shared resources by individuals of different species, where consumption by one species may limit resource availability to other species

competitive exclusion the concept that, if resources are limited, no two species can remain in competition for exactly the same niche indefinitely; also know as Gause's Principle

resource partitioning avoidance of, or reduction in, competition for similar resources by individuals of different species occupying different non-overlapping ecological niches

INVESTIGATION 23.1 *Introduction*

Planting Opposition: Intraspecific and Interspecific Competition

Virtually all naturally occurring organisms are in competition—either with members of their own species (intraspecific competition) or with members of different species (interspecific competition). In this investigation you will design and conduct experiments to measure the effect of both intraspecific and interspecific competition on plant seedlings.

To perform this investigation, turn to page 776.

Report Checklist

- ● Purpose
- ○ Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

WWW WEB *Activity*

Case Study—Gause's Principle

Ecologists describe the struggle for survival in terms of the competitive interactions between different species in nature. Gause was an ecologist who studied the effects of competition on two *Paramecium* species. He grew each species separately in culture tubes, and then put the two together in the same tube. In this Web Activity, you will compare the growth and population densities of the *Paramecium* populations, both separately and together.

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Predation

Predation is an example of an interspecific interaction in which the population density of one species—the predator—increases while the population density of the other species—the prey—declines. Predator–prey relationships can have significant effects on the size of both predator and prey populations. When the prey population increases, there is more food for predators. This abundance can result in an increase in the size of the predator population. As the predator population increases, however, the prey population decreases. The reduction of prey then results in a decline in the predator population, unless it has access to another food source. There are time lags between each of these responses as the predator population responds to changes in prey abundance.

Some predator–prey relationships coexist at steady levels and display a cyclical pattern. The two species tend to cycle slightly out of synchronization, with the predator patterns lagging behind the prey patterns (**Figure 4**). In this model of a predator–prey cycle, adjustments to population size can be seen during the time intervals from A to E. This graph is referred to as a sinusoidal curve. At time A, when the prey population density is low, the predators have little food and their population declines. A reduction in the predator population allows the prey population to recover and increase. The predator population does not increase again until they begin to reproduce (at time B). Prey and predator populations grow until the increase in the predator population causes the prey population to decline (from time C to time E). As the predator population increases, more of the prey population is devoured. The resulting low density in the prey population leads to starvation and lowered fecundity among predators, slowing its population growth rate (at time D).

In nature, many factors can influence this model of the sinusoidal predator–prey cycle. In 1831, the manager of the Hudson's Bay Company in northern Ontario reported that there was a scarcity of snowshoe hares and the local Ojibwa population was starving as a result. In the early 1900s, wildlife biologists began analyzing the fur-trading records of the Hudson's Bay Company. They discovered that the hares have a population cycle of 10 years. The population cycle of the Canadian lynx, a significant predator of snowshoe hares, mirrors, with a slight time lag, the changes in the snowshoe hare population (**Figure 5**).

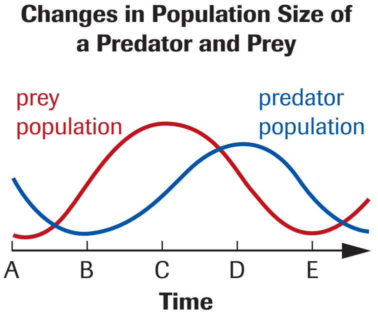

Figure 4
A model of the predator–prey cycle. Because of the oscillations in the populations, the line on this graph is referred to as a sinusoidal curve.

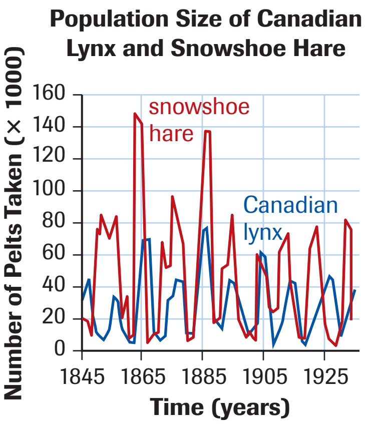

Figure 5
A 10-year cycling pattern in the population of Canadian lynx and the population of snowshoe hare

WWW WEB Activity

Case Study—Elk Management in Banff National Park

Human activities such as agriculture and over-hunting often disrupt the natural balance of wildlife populations. This can lead to a loss or reduction in the home range of a particular species and an associated decline in its population size. Management programs may lead to a recovery of the species. An interesting case of the influence of humans on wildlife populations is the history of the elk that live in Banff National Park, Alberta.

In this activity, you will consider ecological and human/elk issues around elk in the park. You will also assess preliminary results of the Banff National Park Elk Management Strategy on elk population biology.

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EXTENSION

Natural Selection and Predator/Prey Interactions
Find out about the concept of co-evolution and the role that predator-prey interactions play in the evolution of species.

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LAB EXERCISE 23.A

Report Checklist

- ○ Purpose
- ○ Problem
- ● Hypothesis
- ○ Prediction
- ○ Design
- ○ Materials
- ○ Procedure
- ○ Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

Predator–Prey Cycles

The large white-tailed deer population in a forest reserve in Alberta has caused concern about overgrazing that might lead to the extinction of plant and animal species found there. To manage this excessive deer population, forest personnel decided to introduce its natural predator, the wolf (**Figure 6**). In the year 1990, 2000 deer lived within the reserve, and 10 wolves were flown into this reserve. Population densities of white-tailed deer and wolves were monitored for a 10-year period.

Problem

What effect does the introduction of a natural predator, the wolf, into a habitat have on the white-tailed deer population?

Hypothesis

(a) Develop a hypothesis about the effect on the white-tailed deer population as a result of the introduction of wolves into their habitat.

Evidence

Table 2 Changes in White-tailed Deer and Wolf Populations

Year	White-tailed deer	Wolves
1990	2000	10
1991	2300	12
1992	2500	16
1993	2360	22
1994	2244	28
1995	2094	24
1996	1968	21
1997	1916	18
1998	1952	19
1999	1972	19

Analysis

(b) Plot the changes in the white-tailed deer and wolf population using the data in **Table 2**, including both sets of data on one graph and using an appropriate labelling method. Use two separate *y*-axes, one on the left-hand side of the graph for deer and the other on the right-hand side for wolves, each with an appropriate scale.

Evaluation

(c) Is wolf predation a limiting factor in this forest reserve? Explain your reasoning.

(d) What other factors might limit the deer population?

(e) Explain how the number of wolves in the reserve is influenced by the size of the deer population.

Figure 6

Synthesis

(f) The Atlantic cod population was an extremely abundant stock of primary economic importance to fishing communities throughout the Atlantic provinces. The Department of Fisheries and Oceans has stated that the collapse in Atlantic cod stocks can be attributed to overfishing. Others claim that the use of equipment that disturbs fish spawning sites on the ocean floor is primarily responsible, and still others argue that the harp seal, a predator of Atlantic cod, is responsible for this mass reduction in the cod population. One suggestion to help cod stocks recover is to kill large numbers of harp seals. Suggest some ways that marine biologists might study changes to the Atlantic cod population to determine whether reducing the harp seal population would be an effective solution.

DID YOU KNOW?

A Twig or a Caterpillar?

Some prey species use this passive defence mechanism to hide from predators. For example, the inchworm in **Figure 7** is camouflaged, blending in with its surroundings. Camouflage is also called cryptic coloration.

Figure 7

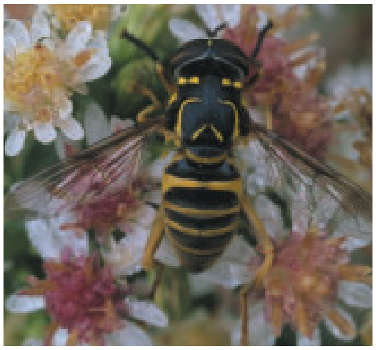

Figure 9
This syrphid fly is less likely to be preyed upon because it mimics stinging bees and wasps.

mutualism a symbiotic relationship in which both organisms benefit; as neither is harmed, it is categorized as a +/+ relationship

commensalism a symbiotic relationship in which one organism benefits and the other organism is unaffected; it is categorized as a +/0 relationship

Defence Mechanisms

Predator–prey interactions have resulted in the evolution of various defence mechanisms in plant and animal species, through repeated encounters with predators over time. Plants use both morphological defences—such as thorns, hooks, spines, and needles—and chemical defences against herbivores. The mustard family of plants, for example, contains oils that give off a pungent odour and make them distasteful and toxic to some insects. Some plants, such as balsam fir, produce chemicals that mimic an insect growth hormone. When a young linden bug (*Pyrrhocoris apterus*) feeds on balsam fir, it remains in the juvenile stage and eventually dies.

Some insects use chemicals produced by their food as a defence against their own potential predators. For instance, the monarch butterfly uses potent plant toxins to make itself distasteful to its predators (**Figure 8**). Caterpillars of the monarch butterfly obtain these toxins by feeding on plants of the milkweed family. The toxins are stored in fatty tissues of the caterpillar, making both it and the adult butterfly unpalatable.

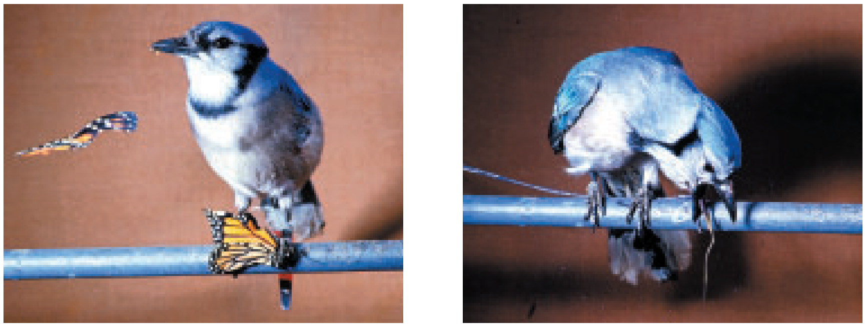

Figure 8
The monarch butterfly and its predator, the blue jay, provide an example of defence mechanisms by prey against predators. Blue jays have been known to regurgitate a monarch butterfly after swallowing it.

Animals sometimes employ passive defence mechanisms, such as hiding, or active defences, such as fleeing from their predators. Active defences are more costly to the prey in terms of energy use than are passive defences. Some species, such as Richardson's ground squirrels, use alarm calls to signal each other when a predator is near. Some animals give a visual warning to predators of their chemical defence mechanisms, such as poisons.

Both predator and prey species can protect themselves through mimicry. In one type of mimicry, a palatable or harmless species mimics an unpalatable or harmful organism, a phenomenon often observed in insects. Predators are often fooled by these mimics who, as a result, avoid predation. A typical example is the harmless syrphid fly that looks remarkably similar to bees and wasps (**Figure 9**).

Symbiosis

Symbiosis, meaning "living together," refers to a relationship in which organisms of two different species live in close, usually physical, contact. At least one of the two species benefits from the association. One type of symbiotic relationship is **mutualism**, which occurs when both species in the relationship benefit and neither is harmed. Most biologists also include as symbiotic relationships **commensalism**, which occurs when one organism benefits and the other neither benefits nor is harmed, and **parasitism**, which occurs when one organism benefits at the expense of another organism's well-being.

Mutualism

There are many common examples of mutualism in which both organisms benefit. Bacteria live in the guts of herbivores, such as cows, deer, and sheep. These animals do not produce the enzymes required to digest plant products such as cellulose and lignin. The bacteria secrete enzymes to break down these products into useable nutrients for the animals. In return, the bacteria are provided with nutrition themselves. Beneficial bacteria also live in the large intestines of humans, producing nutrients such as vitamins B and K, which our cells can use.

Commensalism

It can be difficult to classify a relationship as an example of commensalism. Some biologists argue that they do not exist at all, since it is very difficult to determine whether an individual of the unaffected species is, in fact, benefiting or being harmed. Caribou and Arctic foxes interact in a way that has been classified as commensalistic (**Figure 10**). The foxes follow the caribou herds when they forage for food in their wintering grounds. The caribou have shovel-like feet that can remove snow from lichens on the ground, which is the caribou's primary food source. The caribou expose many small mammals, which are eaten by the foxes. Thus, the foxes benefit from this interspecific interaction and the caribou neither benefit nor are harmed by it. In a similar way, tropical "ant birds" follow army ant colonies through the rainforest, feeding not on the ants but on the other insects and small animals that are disturbed by the ants.

Parasitism

Most parasites live and feed on or in the bodies of other living organisms, and cannot complete their life cycle in the absence of their hosts. Parasitism is extremely common. Biologists estimate that as many as one in four animal species may be parasites. Virtually all species of plants and animals are hosts to one or more species of parasite. While the best-known parasites are responsible for serious human diseases—such as malaria, schistosomiasis, and African sleeping sickness—the vast majority of parasites cause little or no significant harm to their host. This makes sense, since they would be harming the environment on which their own survival relies.

Parasites do not always live on or in another organism. Some species are classified as **social parasites**. These organisms manipulate the behaviour of another species so that they can complete their life cycle. North American cowbirds are social parasites. They lay their eggs in the nests of other smaller birds and, therefore, do not have to expend energy building their own nests or feeding their own young. The cowbird eggs usually hatch earlier and the larger newborn cowbirds monopolize the food resources. The other newborn birds are usually killed, resulting in a very high survival rate for the young cowbirds.

parasitism a symbiotic relationship in which one organism (the parasite) benefits at the expense of another organism (the host), which is often harmed but usually not killed; it is categorized as a +/− relationship

Figure 10
Caribou unknowingly help Arctic foxes by exposing snow-covered habitats of fox prey.

EXTENSION

CBC radio ONE
QUIRKS & QUARKS

Altruism: Why Can't We All Just Get Along?
Dr. Sigal Balshine, Dr. David Sloan Wilson, Dr. Joel Peck, and Dr. Troy Day, discuss their research into interspecific interactions, particularly altruism and co-operation.

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social parasite a parasite that completes its life cycle by manipulating the social behaviour of its hosts

mini Investigation — *Finding a Host*

Internal parasites live in hosts that eventually die, usually due to something other than the parasite. For this reason it is essential that parasites be able to find and invade new host individuals on a regular basis. This is particularly challenging for internal parasites and results in very complex life cycles for these species.

- Choose an internal parasite and research the ways it is able to get from one host to another. Common internal parasites include flukes, tapeworms, *Plasmodium*, and *Trypanosome* species.

(a) Draw the life cycle of your chosen parasite, indicating how it gets from one host to another.

Figure 11
Some African killer bees escaped from Brazilian beekeeping operations and have spread accidentally into North America.

Disruption of Community Equilibrium

Biological communities are stable when the resources necessary for survival are sustained, populations do not exceed their environment's carrying capacity, and interspecific interactions contribute to biodiversity. Interspecific interactions help to maintain the necessary equilibrium within the complex and dynamic natural systems that sustain communities. A variety of disturbances can affect this equilibrium in drastic ways. A natural disaster can disturb most populations within a community and can break down the intricate interactions among its organisms. The introduction of exotic species can have devastating biological and economic effects on the habitats they invade (**Figure 11**). These nonindigenous species, often with few predators, may reduce or eliminate indigenous species by outcompeting them for food and habitat, or by preying on them. Some recent examples of the harmful effects of introducing an exotic species into an ecological community are shown in **Table 3**.

Table 3 Selected Invading Species

Wild caraway (*Carum carvi*)	Grown in Western Canada as a spice crop, non-native "wild" caraway has escaped cultivation. In parts of Alberta this species is now invading pasture, rangeland, and natural habitats. It is not consumed by livestock and when left uncontrolled can quickly outcompete many other plant species.
African killer bees (Figure 11)	These aggressive bees are hybrids of the domesticated European bee and an African bee that was imported to Brazil by scientists. Large numbers of these bees attack much more readily than the common honeybee does. Aside from public safety, Africanized killer bees have a significant economic impact on commercial beekeepers and food production.
West Nile virus	The West Nile virus, detected in wildlife populations throughout North America, was first identified in the West Nile region of Uganda in 1937. It can be transmitted to humans by three species of mosquitoes: *Culex pipiens* (the common household mosquito), *Aedes vexans* (an indiscriminate feeder), and *A. japonicus*. It is responsible for serious wildlife population losses in many parts of the world. The virus is believed to have been accidentally introduced to North America in an exotic frog species.

EXTENSION

Predator-Prey I

In this Virtual Biology Lab, you will explore the effect of changes in populations of predator and prey on population growth, through a series of activities. You can modify factors such as birth rate, death rate, and the level of predation.

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WWW WEB Activity

Web Quest—Zebra Mussels

Shipping is one of the most common methods of transporting goods long distances. Massive transportation networks depend on cutting-edge technology to stay organized and accident-free. Unfortunately, the sophisticated technology needed to run shipping companies has not been able to stop the transfer of unwanted guests from one part of the world to another. In this Web Quest, you will look at the impact of one of these stowaway organisms—the zebra mussel. This exotic species has had a huge impact in its new environment, and you are going to explore the effects of this little bivalve.

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SUMMARY Interactions within Communities

- Predator–prey interactions are affected by a wide range of factors. Both predators and prey have evolved adaptations that enhance survival.
- Symbiosis may result in mutually beneficial relationships between species.
- Commensalism may result in one species indirectly benefiting another.
- Parasitism is an interaction in which one species feeds and lives in or on a host organism to the detriment of the host.
- Invasions by exotic species, human interference, and natural disasters can disrupt the stability of an ecological community.

+ EXTENSION

CBC radio ONE QUIRKS & QUARKS

Mosquitoes versus Malaria

Dr. Ken Vernick and his colleagues have discovered that a large proportion of *Anopheles* mosquitoes have a genetic resistance to the malaria parasite. They are able to kill the parasite as soon as it enters their body, so they can't pass the disease on to humans.

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Section 23.1 Questions

1. For each of the following examples, identify what type of interspecific competition is occurring and justify your answer.
   (a) Argentine ants can displace indigenous ants from a community by rapidly depleting resources.
   (b) Some plants release toxins that kill or inhibit the growth of other plants, thereby preventing them from growing in close proximity where they may compete for space, light, water, and food.
   (c) In the Kibale Forest in Uganda, mangabey monkeys, a large species, drive away the smaller blue monkeys.
   (d) Hawks and owls rely on similar prey, but hawks feed during full daylight while owls hunt and feed from dusk to dawn. What term is used to describe this method of avoiding competition?
2. A study was conducted of mussels and the starfish *Pisaster* in the intertidal area along the shore. Results showed that greater diversity of marine invertebrates was found in the area where *Pisaster* and mussels were present together, compared to where mussels were found alone. Explain this observation in terms of competition.
3. Identify the type of defence mechanism in each of the following examples:
   (a) Tiger moths have a highly detailed wing pattern that makes them virtually undetectable against tree bark.
   (b) When attacked by ants, ladybugs secrete a sticky fluid that entangles ant antennae long enough to allow the ladybug to escape.
4. Explain how predation differs from parasitism.
5. Termites eat wood but cannot digest it. They have unicellular, heterotrophic organisms called zoomastigotes living inside their digestive tract that do this for them. Identify the type of interspecific interaction between the termites and the zoomastigotes.
6. In the Great Smoky and Balsam Mountains, ecologists are studying two species of salamander. *Plethodon glutinosus* usually lives at lower elevations than its relative, *P. jordani*, shown in **Figure 12**, although the researchers have found some areas inhabited by both species. As part of the study, the scientists established different test plots from which one of the species was removed and control plots in which the populations remained untouched. After five years, no changes were observed in the control plots, but in the test plots, salamander populations were increasing in size. For instance, if one of the test plots was cleared of *P. jordani*, it had a greater population density of *P. glutinosus* and vice versa. What inferences or conclusions might be drawn from this investigation?

Figure 12
Salamander *Plethodon jordani*

7. Insects are sometimes used as biological control agents, replacing chemical herbicides to control agricultural weeds. For example, in an area near Edmonton, Alberta, the black dot spurge beetle (*Aphthona nigriscutis*) was released in an attempt to control the leafy spurge, an aggressive weed species. The results were dramatic: a 99 % reduction in spurge density and a 30-fold increase in grass biomass after four years. Research some costs and benefits of using insects as biological controls. Summarize your research on the societal, economic, ecological, and environmental impacts in a PMI chart.

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23.2 Succession

Figure 1
New life begins after a devastating forest fire.

succession the slow, progressive replacement of one community by another during the development of vegetation in any area

climax community the final, relatively stable community reached during successional stages

primary succession the occupation, by plant life, of an area not previously covered by vegetation

secondary succession succession in an area that was previously covered by vegetation and still has some soil

pioneer community the first species to appear during succession

Few things appear as devastating as the destruction of a mature forest by a severe fire. All that remains is a blackened landscape with a few solitary tree trunks starkly pointing to the sky. Within a few weeks, however, the ground will slowly turn green as annual and perennial plants, tolerant of the sunlight and the resulting high soil temperatures, begin to grow and reproduce in a soil made fertile by the mineral content of the ash (**Figure 1**). Within two or three years, shrubs and young trees are evident and growing rapidly. A few years later, an untrained observer would probably never know that the area had once been burned out. Over the long term, a forest will become established and reach maturity. When mature, the forest will remain until another disturbance, natural or human-caused, once again alters the abiotic environment and vegetation.

Along with the changing vegetation is a corresponding progression in the variety of animals (birds, mammals, insects) present. Populations enlarge and then decline as the habitat slowly but surely changes.

The pattern described is not limited to forest communities. Other terrestrial regions of the biosphere, such as prairie and tundra, also show regular regrowth following environmental change. This process is referred to as succession. **Succession** describes the gradual changes in the vegetation of an area as it develops toward a final stable community, called a **climax community**.

There are two types of succession. **Primary succession** occurs in an area in which no community existed previously, for example, after a volcanic eruption or when bare rock or mineral soil is exposed by human activity or from beneath a retreating glacier. Lichens and mosses, usually the first to colonize the bare rock surface, release chemicals that help break the rock into fine soil particles. Slowly, by this break-down and weathering, enough soil and dead organic matter accumulate to support small plants. These plants form a community that begins to support a growing diversity of organisms. Over time, the community changes as new species become established and former species are outcompeted. Eventually, a relatively stable plant community forms. **Figure 2** shows a hypothetical process of succession in a forest ecosystem.

Secondary succession occurs when a community is partially or completely destroyed and its dominant plant species have been eliminated. Such destruction may result from causes such as fire, severe flooding, landslides, or human disturbance. Regrowth after a forest fire is the best-known example of secondary succession. Since soil is already present, the lengthy process of soil formation (seen in primary succession) is not necessary. The first plant community to appear, along with its associated animal species, is referred to as the **pioneer community**. Small plants, such as grasses, are common pioneer species. These plants usually have small wind-borne or animal-borne seeds and can exist in full sun and fluctuating soil moisture and temperatures. Moisture levels often dictate which plants survive. As the vegetation develops, however, new ground-level abiotic conditions are set up. As larger plants grow and provide shade, the soil temperature becomes somewhat lower and evaporation is reduced. Decay processes increase the thickness and fertility of the soil layer. Small woody shrubs may then begin to grow, and a new community of plants begins to take over. These plants tend to be taller than the pioneer plants, effectively blocking out much of the solar radiation and contributing even more to the changing microclimate and soil conditions. Often, tree species displace smaller shrubs and form forest communities.

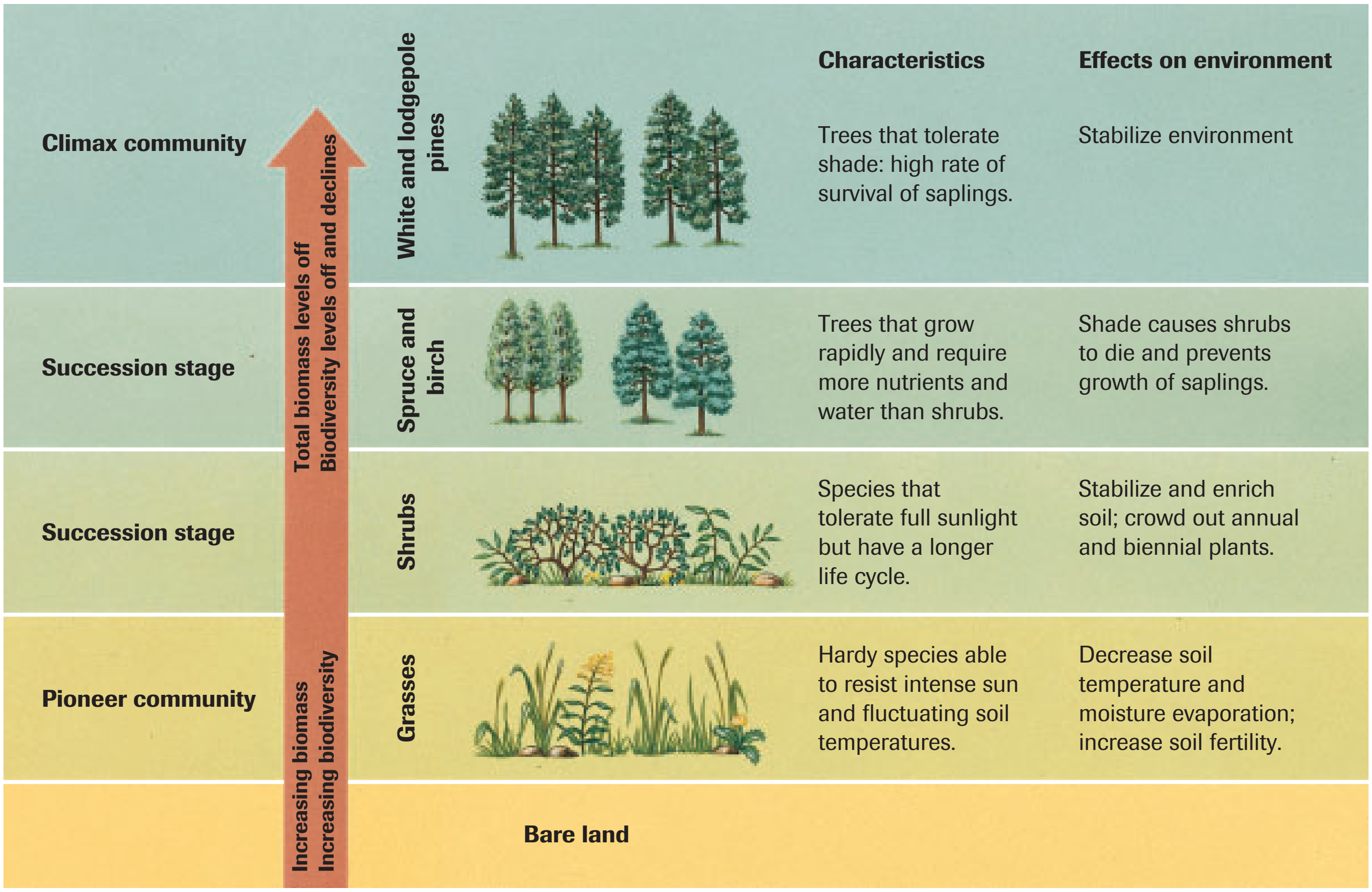

Figure 2
Secondary succession

Just as the plant communities change, so do the ecological niches available to the other species in these communities. As a result, there is a parallel succession of animal, fungal, protist, and bacterial species. Their activities and wastes contribute to the community development. The community continues to change until a final community is reached that can self-perpetuate. This is called the climax community. The process of succession is closely linked to changes in species diversity, net productivity, and biomass. **Figure 3** illustrates the general trends in these factors over 160 years of succession.

While this traditional view of orderly succession provides a good theoretical model of how plant communities change and respond to disturbances, ecologists now recognize that gradual succession, leading directly to a stable climax community, is rare. Instead, successional changes are highly variable and often influenced by frequent and variable disturbances, which can prevent an area from ever reaching a climax community. For example, once they are established, many natural grasslands are maintained by routine fire disturbance—preventing succession to a forest community. Climax communities, if and when established, are in a state of dynamic equilibrium, dominated by the climax vegetation but usually containing extensive areas of vegetation representing earlier stages.

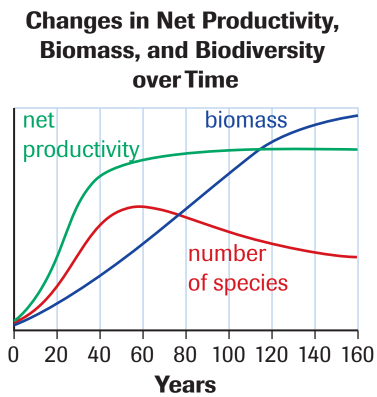

Figure 3
Successional changes in plant communities are accompanied by changes in the net productivity, biomass, and species diversity.

The pattern of succession can also vary between biomes. For example, following a forest fire in a boreal forest biome, the vegetation begins to grow rapidly, as secondary succession commences. The rich vegetation may attract large herbivores, such as deer and moose. However, in a taiga biome, the reverse is possible. Due to the cold climate, lichens, a major food source for the woodland caribou, are extremely slow growing. A fire in these regions may result in a massive decline in the caribou population.

EXTENSION

Succession and *r* and *K* Reproductive Strategies
The dominant organisms at different stages of succession often have different reproductive strategies. This Audio Clip will highlight the different reproductive strategies commonly found in organisms in pioneer communities versus those in climax communities.

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Generalizations about Succession

- Plant succession is triggered by one or both of these factors: disturbances that provide new habitats and removal of previously dominant plant species.
- Succession generally follows a pattern in which smaller pioneer species are replaced by larger species over time.
- Most plant communities exist in a state of flux, with disturbances producing a mosaic of patches in different stages of succession.
- The total number of species increases dramatically during the early stages of succession, begins to level off during the intermediary phases, and usually declines as the climax community becomes established.
- Net productivity generally increases rapidly during the early stages and then levels off.
- Biomass increases during succession and begins to level off during the establishment of the climax community.

WWW WEB Activity

Case Study—Wildfires and Succession

In many terrestrial ecosystems, wildfires play an important ecological role as part of the natural cycle of renewal. Evidence of wildfires can be found in petrified wood dating back nearly 350 million years. A fossilized charcoal, called fusain, is found in the petrified trees once scarred by burning. In this Web-based Case Study, you will evaluate the role of wildfires in two types of ecosystems found in Alberta and elsewhere, forests and grasslands.

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INVESTIGATION 23.2 *Introduction*

Microbial Succession

Ecological succession can describe any set of predictable changes that result in the transition of living communities over time. Successional changes can even occur in environments inhabited almost exclusively by microbes. In this investigation, you will document changes in microbial communities in a hay infusion.

To perform this investigation, turn to page 777.

Report Checklist

Purpose	Design	Analysis
Problem	Materials	Evaluation
Hypothesis	Procedure	Synthesis
Prediction	Evidence	

SUMMARY Succession

- Succession is the series of predictable gradual stages as living communities change over time.
- Primary succession occurs on a barren landscape where no community existed previously.
- Secondary succession occurs after a previous community suffers complete or partial destruction.
- Each stage of succession may be recognized by the presence of one or more characteristic dominant species.

EXTENSION

Wildfires and Succession

You have read about the process of succession. Now, listen to this Audio Clip discussing why non-climax species "sow the seeds of their own destruction." What does this mean for climax species?

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Section 23.2 Questions

1. Distinguish between primary and secondary succession. Which of these processes would you expect to proceed more rapidly? Explain your reasoning.
2. What is meant by a climax community? How would you recognize a climax forest community?
3. Describe three ways in which pioneer plants alter the environment to make it more suitable for later-stage species. Describe two ways in which later-stage species alter the environment to make it less suitable for pioneer species.
4. Name two human activities that can result in secondary succession.
5. Why does succession proceed in a series of stages?
6. Aspen trees produce many extremely lightweight seeds that are carried long distances by the wind. In contrast, oak trees produce relatively small numbers of heavy seeds that fall to the ground and may be carried short distances by foraging animals.
   (a) Which species would you expect to be an early succession species and why?
   (b) What advantage might a large seed give to a plant that must germinate and survive in a late-stage mature forest with heavy shade?
   (c) Would you expect pioneer or late-stage plant species to be more tolerant of dry conditions? Explain.
7. Jack pines produce cones with a waxy outer coating that protects the seeds from extreme heat. After exposure to very high temperatures, the cones open and release their unharmed seeds.
   (a) How does such an adaptation make jack pine a secondary succession specialist?
   (b) How might human forest fire management programs alter the ecology of jack pine forests?
8. Over time, small shallow ponds and bogs can become filled in with sediment and organic matter, eventually becoming forested land. Research the formation of a peat bog and the process of succession in it.
   (a) Describe the mechanisms by which sphagnum moss is able to cover the bog.
   (b) Describe the process by which peat deposits accumulate over time.
   (c) Draw or obtain an image of a cross-sectional view of peat bog formation/succession.

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9. Disturbances occur on many scales. In a forest, small disturbances include the deaths of individual trees that create openings or gaps in the canopy. Large-scale disturbances include forest fires. Modern forestry cutting practices can be used to mimic both of these disturbance scales. Obtain reference materials from the forestry industry and/or a government agency, and use the information you find to answer the following:
   (a) What is a shelter-wood cut? When is this cutting practice chosen and how does it mimic natural disturbances?
   (b) What is a clear-cut? When is this cutting practice chosen, and how does it mimic natural disturbances?
   (c) What are the similarities and differences between these forms of human disturbance and those that they are supposed to mimic in nature?

INVESTIGATION 23.1

Plant Opposition: Intraspecific and Interspecific Competition

Report Checklist

- ● Purpose
- ○ Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

Virtually all organisms are in competition, both with members of their own species (intraspecific) and with members of different species (interspecific). Unlike most animals, individual plants cannot move to new locations to avoid or reduce competition; they are constantly in direct competition with their immediate neighbours. Plants compete for a variety of resources, including physical space, soil nutrients, light, and water. In the short term, such competition may result in a reduction in the growth rate or health of individual plants, while in the long term, competition may result in reduced reproductive success or death of some of the plants.

In this investigation you will design and conduct experiments to measure the effect of both intraspecific and interspecific competition on plant seedlings.

Problems

Part 1: Intraspecific Competition

Does the presence of other plants from the same species affect the growth of individual plants?

Part 2: Interspecific Competition

Does the presence of plants from other species affect plant growth differently from the presence of plants from the same species?

Materials

small plant pots
soil mix
plant seeds (variety of species)

Design

Design an investigation and write a detailed procedure to address each problem. Consider coordinating your investigations with those of other groups to maximize the amount of data that you are able to include in your analysis. Groups that share data must use identical experimental designs.

Your design and procedure must include the following:

- clearly stated and testable hypotheses for both your intraspecific and interspecific competition experiments
- independent and dependent variables including a proper control
- careful monitoring of your experiments and gathering and recording of evidence (How will you determine if competition has taken place?)

Once your teacher has approved your design, carry out your procedure. Make sure you follow appropriate safety measures.

Analysis and Evaluation

(a) How did intraspecific competition influence plant growth rates in your trials? Was the effect the same for all species? Suggest explanations to account for any differences.

(b) In your interspecific competition trials, did both plant species suffer from competition equally or did one species appear to "out-compete" the other?

(c) Did you notice any differences between the competing plants and the controls? (For example, did they appear to grow taller?) Did this demonstrate an adaptive response to competition?

(d) Predict the long-term results of both forms of competition if you allowed your plants to continue growing for a year.

(e) The plant seedlings in your experiments may have competed for a variety of environmental resources.
   (i) What do you think were the direct causes of any observed effects? Identify which factor(s) had a role in the competition effects: limited access to light, nutrients, space, or water.
   (ii) Suggest a modification to your experimental design that could be used to test your answer in question (e), part (i), above.

Synthesis

(f) Most plants have obvious adaptations for seed dispersal. Explain how each of the following features enhances seed dispersal.
   (i) the seed head of a dandelion
   (ii) the colourful and tasty fruits of apples and strawberries
   (iii) the hooks on a burr
   (iv) the wing of a pine seed

INVESTIGATION 23.1 *continued*

(g) Do the adaptations in question (f) reduce intraspecific or interspecific competition? Explain.

(h) Most agricultural operations attempt to minimize the influence of competition. Plants that compete with crops are called "weeds" and are often destroyed using herbicide applications or by mechanical removal and cultivation. Conduct research to answer the following:
   (i) What is the most widely used herbicide in Alberta? Approximately how many tonnes are applied each year?
   (ii) List four important weed species in Alberta crops.
   (iii) List the most important advantages and disadvantages of using herbicides to reduce competition with weeds.

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(i) The forestry industry also manages intraspecific and interspecific competition by using a variety of silviculture practices. Conduct research to determine how forestry companies reduce competition from non-commercial plant species and how they manage the competition between individuals of valuable species.

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(j) Allelopathy, the equivalent of underground chemical warfare, is a strategy employed by many plant species to reduce competition. Research allelopathy and report your findings back to the class.

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INVESTIGATION 23.2

Microbial Succession

Ecological successional changes occur in every inhabited environment on Earth: the surface of a rotting log, the lichens that colonize barren rock, and the development of large coral reefs. Among the least obvious are those that occur in environments inhabited almost exclusively by microbes.

Bacteria and protists fill a variety of ecological niches, including photosynthetic producers, gut symbionts, pathogens, and decomposers. In this investigation you will use a hay infusion to study succession in a microbial community.

Report Checklist

Purpose	Design	Analysis
Problem	Materials	Evaluation
Hypothesis	Procedure	Synthesis
Prediction	Evidence	

Design

In this part of the Investigation, you will design an investigation to observe changes in the microbial populations of a hay infusion. Read the procedure for preparing the hay infusion. Then, generate a hypothesis concerning the relationship between factors such as rates of population growth, types of microorganisms, changes in microbe diversity over time, etc. Your design must enable you to judge the validity of your initial hypothesis.

- How can you test your hypothesis regarding population growth of microbes in the hay infusion?

Write a procedure that will allow you to test your hypothesis. Your procedure must include steps in which you monitor and record the changes that take place in the microbial community over a period of two to three weeks.

- How will you obtain samples of the infusion? Should you sample from different depths in the beaker?
- What equipment and references will you need in order to observe and identify different micro-organisms?
- What safety measures must be observed?
- Will you attempt to quantify the populations of each species, and if so, how?
- How will you record the evidence?

Write a prediction for your experiment.

Materials

2 beakers (250 mL)
water
scissors
hay
hotplate
stirring rod
sieve
distilled water
watch glass or Petri dish lid (to cover one beaker)

Procedure

1. Loosely fill a 250 mL beaker with coarsely chopped hay. Fill the beaker to the 200 mL mark with water.
2. Bring the hay and water to a boil, stirring occasionally, and allow to simmer for 10 minutes.
3. Let the mixture cool overnight.
4. Using the sieve and the second beaker, separate the yellowish infusion from the cooked hay. Discard the hay. Top up the infusion to 200 mL using distilled water.
5. Cut some fresh dry hay into tiny pieces, less than 5 mm in length. Add about 10 mL of this cut hay to your infusion.
6. Cover the beaker with a watch glass or the lid from a Petri dish.
7. Add distilled water as needed to replace water lost due to evaporation.

Analysis

(a) Which types of microbes, bacteria or protists, grew first in the infusion? Suggest an explanation for this observation.

(b) What was the source of the organisms in the infusion? From where did these species originate?

(c) How might a microbe's ability to form resistant spores or cysts enhance its biological success?

(d) How might the order of appearance of the microbes be related to their place in a food chain?

(e) Was there any evidence of photosynthesizing organisms?

(f) Even if no producers are present, an infusion will support a large community of micro-organisms. What is the primary energy source supporting the food chain in such a system?

Evaluation

(g) Modify your procedure so that you could observe microbial succession in an environment that
(i) had a higher concentration of oxygen gas,
(ii) had a higher (or lower) pH, and
(iii) modelled the internal gut environment of a mammal.

Chapter 23 SUMMARY

Outcomes

Knowledge

- describe the basis of species interactions and symbiotic relationships and their influences on population changes (23.1)
- explain the role of defence mechanisms in predation and competition as caused by genetic variation (23.1)
- explain how mixtures of populations that define communities may change over time or remain as a climax community, i.e., primary succession, secondary succession (23.2)

STS

- explain why Canadian society supports scientific research and technological development that helps achieve a sustainable society, economy and environment (23.1)

Skills

- ask questions about observed relationships, and plan investigations (all)
- conduct investigations and gather and record data and information by designing and performing: an experiment or simulation to demonstrate interspecific and intraspecific competition (23.1); an experiment to demonstate succession in a microenvironment and recording its pattern of succession over time (23.2); and by performing simulations to investigate relationships between predators and their prey (23.1)
- analyze data and apply mathematical and conceptual models by summarizing and evaluating a symbiotic relationship (23.1)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

23.1

symbiosis
interspecific competition
interference competition
exploitative competition
resource partitioning
mutualism
commensalism
parasitism
social parasite

23.2

succession
climax community
primary succession
secondary succession
pioneer community

MAKE a summary

1. Relationships between populations in a community can harm, benefit, or have little or no effect on each population. For each pair, summarize how each species influences the actions of the other. Consider the impact on the entire population as well as on individual members.
   (a) lynx and snowshoe hare
   (b) pioneer plant species and later-stage plant species
   (c) internal parasites and their host species
   (d) Arctic fox and caribou
   (e) honey bees and flowering plants
   (f) monarch and viceroy butterflies
   (g) *Parmecium aurelia* and *Paramecium caudatum*
   (h) an invasive species and a native species sharing similar ecological niches
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 23
- additional Diploma Exam-style Review Questions
- Illustrated glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

EXTENSION

Issues and Impacts—Fire Ants in the Pants
Fire ants are an imported species that are out-competing native ant species in the southern United States. What strategies are being used to re-establish a more natural balance?

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UNIT 30 D PERFORMANCE TASK

Changes in Human Population Size

The human population can be analyzed in the same way as the population of any other organism, using the tools and knowledge you acquired in this unit. In this Performance Task, you will work in a group to decide if you support or refute this statement: "The human population is growing at an alarming rate and is rapidly approaching Earth's carrying capacity."

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Chapter 23 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Which of the following best describes a commensal relationship?
A. One species benefits and the other is usually killed.
B. One species feeds on a host species but the host is usually not seriously harmed.
C. One species benefits and the other is usually unaffected.
D. Both species benefit.

2. According to the concept of competitive exclusion
A. no two species can successfully occupy the same habitat at the same time
B. two members of the same species cannot share the same territory
C. no two species can successfully occupy the same ecological niche in the same region
D. using the same resources often leads to the establishment of a mutualistic relationship

3. Which of the following best describes predator–prey relationships?
A. Predators out-number prey and their population growth lags behind that of their prey.
B. Prey out-number predators and their population growth lags behind that of the predators.
C. Predators out-number prey and their population growth precedes that of their prey.
D. Prey out-number predators and their population growth precedes that of the predators.

4. NR Place the following successional events in the proper sequence. (Record all four digits of your answer.)
1. Shade-tolerant species begin to become established.
2. Taller, shade-intolerant species become dominant.
3. Species that are resistant to high temperatures and dry conditions are abundant.
4. A community of plants exhibits little change over long periods of time.

Part 2

5. For each of the photographs in **Figure 1**, **identify** the defence mechanism used by each species.

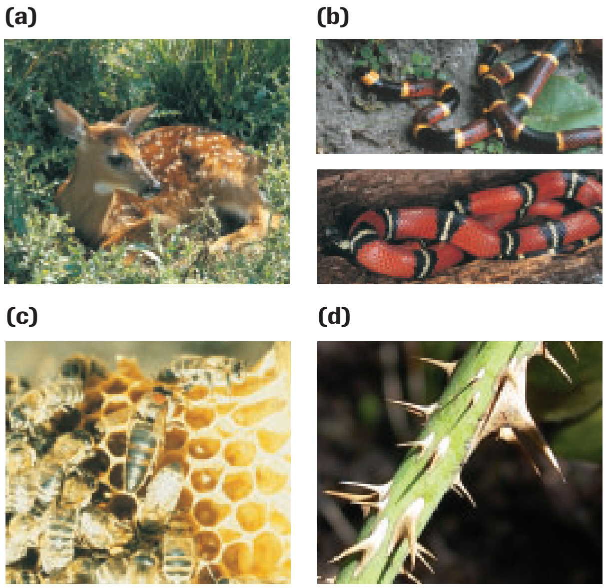

Figure 1
(a) white-tailed deer fawn
(b) venomous Eastern coral snake (top) and harmless Sinoloan milk snake (bottom)
(c) African killer bees
(d) rose

6. In one type of mimicry, several unrelated animal species, all of whom are poisonous or dangerous, resemble one another. For example, monarch and viceroy butterflies have evolved similar coloration (**Figure 2**). **Predict** how this similarity might affect bird species that prey on insects.

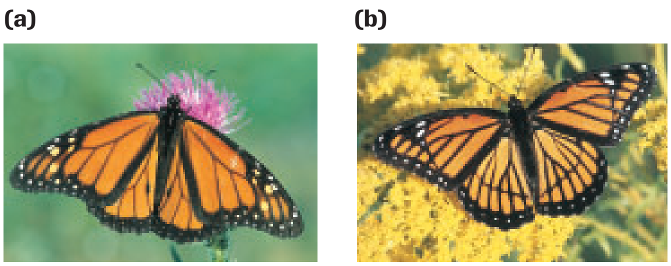

Figure 2
(a) a monarch butterfly
(b) a viceroy butterfly

7. **Explain** why it would be a mistake to eliminate a major predator from a community.

8. **Compare** predators and parasites.

9. DE In an Arctic ecosystem, a fox population begins to prey on small herbivores, such as mice and hares. Caribou are large herbivores that compete for many of the same plants as smaller herbivores. In a unified response, address the following aspects of the changes in this ecosystem:
- **Predict** how the foxes' predation of herbivores will affect the population of plants.
- **Explain** the role of carrying capacity on the size of the population of plants.
- **Predict** how the caribou population will change.

Use the following information to answer questions 10 to 12.

Human activity over the past century extirpated wolves from northern Montana. Coyotes were occupying the habitat as the largest member of the canid family. As a growing wolf population from Alberta invaded the coyotes' territory, Canadian researchers documented the changes in coyote behaviour (**Table 1**).

Table 1 Coyote Behaviour

Before recolonization by wolves
• Coyotes usually were found alone or in pairs.
• Coyotes fed on rabbits, hares, and some plants.
• Coyotes were most active during the early morning and late evening.
• The coyote population was relatively large.
After recolonization by wolves
• Coyotes tended to be found in pairs or small packs.
• Coyotes relied on larger prey and scavenged wolf kills.
• Coyotes avoided times when wolves were active during the winter months.
• Coyotes maintained historic activity patterns during the summer months.
• Coyote population decreased significantly but remained stable.

10. **Describe** the evidence that suggests that the niches of wolves and coyotes overlap.

11. Wolves are known as predators of coyotes. **Identify** the behavioural changes by the coyotes that are likely to reduce the number taken by wolves.

12 Wolves have a dramatically smaller home range in summer when they stay closer to their dens. Does the coyote behaviour seem to account for this change? **Explain**.

Use the following information to answer questions 13 and 14.

The cowbird, a social parasite, lays its eggs in the nests of other birds. The relationship between cowbirds and large grazing mammals is also an example of commensalism. The cowbirds follow migrating herds of mammals, feeding on insects disturbed by the movement of the mammals as they graze. Historically, adult cowbirds were associated with herds of plains bison.

13. **Predict** how the behaviour of cowbirds might have evolved differently if the herds of bison remained in the same small area for weeks at a time during the cowbirds' breeding season.

14. Cowbirds are an open-field species and rarely parasitize nests that are located deep in wooded areas. **Predict** how large-scale clear-cutting of forests might influence the success of this species.

15. Research the sea lamprey, a non-indigenous species, which has had a great impact on the fish communities of the Great Lakes, and then answer the following questions based on your finding:

(a) **Describe** the fundamental and realized niche of the sea lamprey.

(b) **Describe** how sea lampreys may have entered the Great Lake ecosystem.

(c) **Identify** the interspecific interactions of the sea lamprey and its effects on the Great Lakes.

(d) **Describe** some economic setbacks faced by Canadian fisheries as a result of sea lamprey invasion and outline any control efforts.

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16. In 1883, a massive volcanic eruption obliterated half of the island of Krakatau and covered the remainder in ash and pumice, 30 m thick. All previous life was wiped out. Conduct research to learn about the re-colonization of this island by plants and animals.

(a) **Identify** the length of time it took for plants and animals to become re-established on the island.

(b) **Explain** whether the process of succession was rapid or slow.

(c) Do you think the presence of a thick ash layer enhances or inhibits the rate of primary succession? **Explain**.

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Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. The bottleneck effect
- A. increases genetic variability thus leading to evolutionary change
- B. results in lower genetic variation within the population resulting in lower viability
- C. refers to the movement of a small number of individuals into a new environment
- D. is an example of evolutionary change due to natural selection

2. Which of the following choices gives three types of symbiotic relationships?
- A. predator–prey, parasitism, commensalism
- B. mutualism, parasitism, commensalism
- C. predator-prey, mutualism, commensalism
- D. parasitism, mutualism, predator–prey

3. It was observed that as the number of night-time flying insects increases in a region, the population of insect-eating bats also increases. This is an example of
- A. density-dependent, intraspecific competition
- B. density-independent, intraspecific competition
- C. density-dependent, predator–prey relationship
- D. density-independent, predator–prey relationship

4. Which of the following is *not* a defence mechanism?
- A. camouflage
- B. leaf toxins
- C. interference competition
- D. mimicry

5. What is the change in population size if natality = 22, immigration = 6, emigration = 7, and mortality = 14?
- A. 7
- B. 9
- C. –5
- D. 23

6. It was estimated that an original population of 74 bull trout in a section of stream increased in number to 110 over three years. The annual population growth rate and per capita growth rate were
- A. 36 and 3
- B. 12 and 3
- C. 36 and 0.49
- D. 12 and 0.49

(Note that units are intentionally omitted.)

7. NR In each of the following, a change in the ecosystems affects the size of a population in the ecosystem:
1. Fertilizer run-off causes an increase in the algae population in a freshwater lake.
2. The introduction of a predator causes a decline in a population size of snow geese.
3. A fatal infectious disease spreads through a poultry farm and causes a decline in the number of chickens.
4. Habitat loss due to urban expansion causes a decline in the population size of grizzlies.

Identify the statements which describe change due to a density-independent factor. (Record all three digits of your answer.)

8. NR Place the following plants in proper sequence from earliest to latest in primary succession. (Record all four digits of your answer.)
1. lichens
2. shrubs
3. trees
4. grasses

9. NR Match the description with the term. (Record all four digits of your answer in the order of the descriptions.)

___ A small population is isolated on an island.
___ Bacteria are observed to become increasingly resistant to antibiotics.
___ Individuals from one population join another.
___ A new trait appears in the population.

1. mutation
2. sexual selection
3. founder effect
4. migration

10. Which of the following is *not* true regarding succession?
- A. Primary succession usually begins on bare rock or volcanic ash.
- B. Secondary succession is the second stage that follows primary succession species.
- C. Many climax species are shade-tolerant.
- D. Fires are a primary cause of secondary succession.

11. Which of the following are all characteristics of primary successional species?
- A. moisture-loving, sun-loving, long-lived
- B. moisture-loving, shade-loving, long-lived
- C. drought-resistant, shade-loving, long- lived
- D. drought-resistant, sun-loving, short-lived

12. NR A forest fire removes all vegetation from an area. Place the following species in the order in which you would expect them to appear during succession. (Record all four digits of your answer.)
1. slow-growing pine trees
2. grasses
3. fast-growing spruce trees
4. shrubs

Part 2

13. **Define** *evolution* in terms of gene frequencies.

14. **Outline** in a list the conditions that must be met to maintain Hardy–Weinberg equilibrium.

15. DE Genetic changes resulting from mutation can be harmful, beneficial, or neutral. Write a unified response that addresses the following aspects of the relationship between mutations and changes in the gene pool of a population.
    - **Explain** how harmful mutations have little or no influence on the gene pool of a population.
    - **Describe** how beneficial mutations, though more rare, can cause dramatic long-term changes on the gene pool.

Use this information to answer questions 16 and 17.

A recessive allele (*l*) codes for lactose intolerance in humans. As they get older, people who are lactose intolerant lose the ability to digest the lactose sugar in milk. Homozygous dominant (*LL*) and heterozygous individuals (*Ll*) do not have this problem. In Australians of European descent, the incidence of lactose intolerance is only 4 % while 85 % of Australian Aborigines are lactose intolerant.

16. **Determine** the *L* and *l* allele frequencies for these two groups of people.

17. Europeans have a long history of drinking milk from domesticated animals while Aboriginal peoples do not. **How** might this explain such a marked difference in these frequencies? **Relate** your answer to the assumptions required to maintain Hardy–Weinberg equilibrium.

18. Students sampled aquatic insect larvae living on a small section of river bottom measuring 2.0 m by 0.8 m. They found approximately 45 000 black fly larvae in the sample.
    (a) **Determine** the population density of this species.
    (b) **Determine** an estimate of the number of black fly larvae living in a similar habitat of river bottom measuring 50 m by 10 m.

19. According to the 2001 census, the population of Canada had reached 30 007 094 people.
    (a) **Determine** the population density of Canadians, if Canada's land area is 9 976 000 km^2.
    (b) Using our population as an example, **explain** why the ecological density of a species is usually greater than its crude density.

20. **Outline** in a list five environmental resources for which there might be intraspecific competition. **Illustrate** each with an example.

21. DE Natality, mortality, immigration, and emigration are all terms that may apply to any population. Write a unified response addressing the following aspects of these processes:
    - **Describe** briefly what each term means.
    - **Explain** briefly how each process affects a population.
    - **Identify** which of the terms do *not* relate to a closed population. **Explain** why not.
    - **Outline** in a list several examples of closed populations that occur naturally. **Outline** in a second list examples of closed populations produced by human intervention or other activities.

22. DE **Describe** the changes in population size that give rise to the zig-zag pattern visible in **Figure 1**. Explain why this population growth pattern is so common.

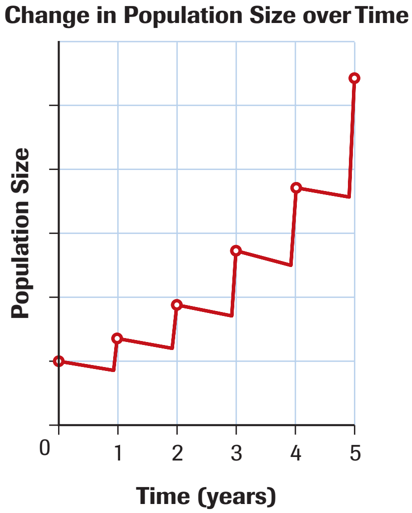

Figure 1

23. **Explain** why small populations often experience relatively slow growth for several generations. **Identify** the name given to this region of slow growth on a sigmoidal curve.

24. **Identify** the conditions that are necessary for a population to experience prolonged exponential growth.

25. **Explain** what happens once a population reaches a dynamic equilibrium.

26. Study the graphs of two different populations in **Figure 2**, on the next page. One graph shows a population of bacteria growing in a laboratory, and the other graph shows a population of owls living in a forest. **Identify** which graph represents which population. **Explain** your reasoning.

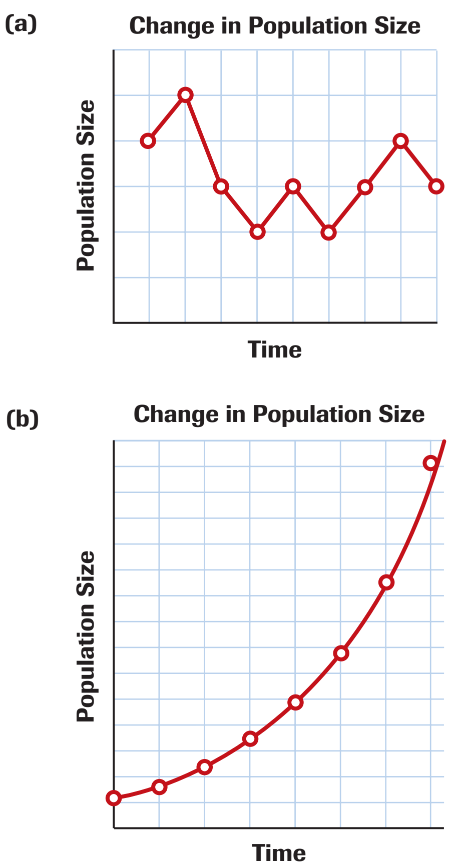

Figure 2

27. **Explain** and **illustrate** with an example the differences between intraspecific and interspecific interactions.

28. **Describe** the obvious defence mechanism utilized by the sea urchin, *Stronglyocentrotus franciacanus*, shown in **Figure 3**. **Infer** the possible adaptive benefit(s) of its bright coloration.

Figure 3
Sea urchin

29. **Describe** and **illustrate** with two examples, each of the following:
(a) commensalism
(b) mutualism
(c) parasitism

30. In a laboratory, researchers placed a *Paramecium* species in a test tube with its predator protozoan. After time, predator–prey cycles became shortened and the system collapsed. The researchers now plan to repeat the experiment with new *Paramecium* being added to the test tube every few days. Write a unified response that addresses the following aspects of the interactions between these two species.
- **Sketch** a graph that shows the changes in the predator and prey populations in the first experiment. Explain the shape of the curves on your graph.
- **Why** did the system collapse in the first experiment?
- **Predict** what the predator-prey cycle will be like in the second experiment. Provide reasoning for your answer. **Justify** your response.

Use the following information to answer questions 31 to 33.

Meadow voles, sometimes referred to as field mice, are extremely common small rodents that breed actively throughout the year with females becoming fertile at under two months of age. The data in **Table 1** represent the growth over time of a population of these voles living in a small grassland.

Table 1 Monthly Growth for a Population of Meadow Voles (Field Mice)

Month	Meadow vole population
December	3 920
January	5 488
February	7 683
March	10 756
April	15 058
May	21 081
June	29 513
July	41 318
August	57 845
September	80 983
October	113 376

31. DE Represent the data **graphically**.

32. DE Based on your graph, **infer** whether the meadow vole population is exhibiting logistic or exponential growth. **Explain**.

33. DE Using your graph, **determine** an estimate of the size of the vole population after three more months.

34. DE **Table 2** compares Canadian population statistics for the periods 1861–1871 and 1991–1996. In 2004, the number of immigrants was about 236 000 while the number of emigrants was approximately 61 000. Write a unified response that addresses the following aspects of these data.

- **Determine** Canada's annual per capita birth and death rates between 1861 and 1871.
- **How** did these values change over the next 120 years? **Hypothesize** reasons for these changes.
- **Determine** the annual per capita growth rate for these two time intervals.
- **Conclude** whether the 2004 values follow the trend(s) in the previous values.

Table 2 Canadian Population Statistics

	1861–1871	1991–1996
starting population	3 229 000	27 852 000
births	1 370 000	1 936 000
deaths	760 000	1 024 000
immigrants	260 000	1 137 000
emigrants	410 000	229 000

35. DE Over the past few hundred years, humans have developed technologies that enable us to drastically alter Earth's environment and influence its carrying capacity for our species. Recently, humans have even placed rovers on the surface of Mars. The rovers have gathered extensive data on the physical characteristics of the "red planet." Data from these and other sources are compared with similar data from Earth in **Table 3**. Write a unified response that addresses the following aspects of the environments of Earth and Mars.

- **Compare** the abiotic features of the two planets that influence their carrying capacity for human life.
- **Identify** the factors that will have to be altered in order to increase the carrying capacity of the planet, if humans are ever to inhabit Mars.
- **Outline** in a list the aspects of our own planet's abiotic and biotic features that we have altered to increase the short-term carrying capacity for the human population.
- **Describe** the impacts that humans are having on Earth that may be decreasing the long-term carrying capacity of Earth.
- Do you think that Mars could support as many humans as Earth in the future? **Justify** your answer.

Use the following information to answer questions 36 to 39.

Researchers recorded the number of individuals in two populations over 8 years. Their data are shown in **Table 4**.

Table 4 Changes in Size of Population A and B

Time (years)	0	1	2	3	4	5	6	7	8
Size of population A	40	60	85	120	170	235	340	330	70
Size of population B	20	25	30	50	115	160	145	155	150

36. DE **Sketch** a graph of the two sets of population data in **Table 4**. on Include the data for both populations on the same set of axes.

37. DE **Identify** which population shows a J-shaped growth curve, and whether its growth pattern is logistic or exponential.

38. DE Between years 5 and 8, both populations show quite different growth patterns. **Explain** the role of the environment in causing these changes.

39. DE **Identify** the species that has a growth curve similar to that of a *K*-selected species. Add a labelled horizontal line to indicate **graphically** the approximate carrying capacity of environment for that species.

40. Review the focusing questions on page 710. Using the knowledge you have gained from this unit, briefly **outline** a response to each of these questions.

Table 3 Abiotic and Biotic Factors on Earth and Mars

	Earth	Mars
atmosphere	thick, 78 % nitrogen gas, 21 % oxygen gas	less than 1 % as dense as that of Earth > 95 % carbon dioxide gas, 0.15 % oxygen gas
weather	highly variable, precipitation in the form of rain and snow	no precipitation, dust storms common
cosmic radiation	mostly shielded by magnetic field	bombardment strong due to weak magnetic field
temperature	highly variable, ranges from extremes of –50 °C to +50 °C	generally very cold with an average of –55 °C.
water	covers over 50 % of Earth's surface; extensive ice caps and cloud cover	present but frozen below the surface, none in liquid form.
life	estimates of 10–30 million species including humans	no known life; microbes remain a possibility
hours/day, days/year	24 h, 365 d	24.5 h, 670 d